

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
18 August 2005 (18.08.2005)

PCT

(10) International Publication Number
WO 2005/076084 A1

(51) International Patent Classification⁷: G03F 7/20

(21) International Application Number:
PCT/EP2005/000641

(22) International Filing Date: 24 January 2005 (24.01.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/542,924 9 February 2004 (09.02.2004) US

(71) Applicant (for all designated States except US): CARL ZEISS SMT AG [DE/DE]; Carl-Zeiss-Strasse 22, 73447 Oberkochen (DE).

(72) Inventors; and

(75) Inventors/Applicants (for US only): ROSTALSKI, Hans-Jürgen [DE/DE]; Dietrich-Bonhoeffer-Strasse 9, 73447 Oberkochen (DE). DODOC, Aurellian [DE/DE]; Hainbuchenweg 7, 73447 Oberkochen (DE).

(74) Agents: SCHWANHÄUSSER, Gernot et al.; Ostertag & Partner, Eibenweg 10, 70597 Stuttgart (DE).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declaration under Rule 4.17:

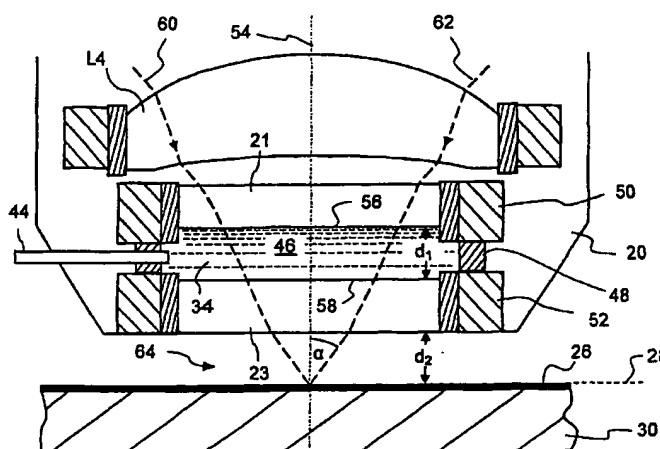
— of inventorship (Rule 4.17(iv)) for US only

Published:

— with international search report

[Continued on next page]

(54) Title: PROJECTION OBJECTIVE FOR A MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS



(57) Abstract: A projection objective of a microlithographic projection exposure apparatus (10) has a last optical element (23; 123; 223; 323; 423) on the image side which is plane on the image side and which, together with an image plane (28) of the projection objective (20; 120; 220; 320; 420), delimits an immersion space (64) in the direction of an optical axis (54) of the projection objective, which can be filled with an immersion liquid. At least one liquid or solid volume (34, 46, 34a, 34b, 246a, 246b; 334; 434) having plane-parallel interfaces can be introduced into the beam path of the projection objective (20; 120; 220; 320; 420), the optical thickness of the at least one volume (34, 46, 34a, 34b, 246a, 246b; 334; 434) being at least substantially equal to the optical thickness of the immersion space (64). By introducing and removing the volume, it is possible to convert the projection objective from dry operation to immersed operation in a straightforward way, without extensive adjustments to the projection objective or alignment work being necessary for this.



— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

**PROJECTION OBJECTIVE FOR A
MICROLITHOGRAPHIC PROJECTION EXPOSURE APPARATUS**

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a projection objective for microlithographic projection exposure apparatuses, such as
5 those used for the production of large-scale integrated electrical circuits and other microstructured components.

2. Description of Related Art

Integrated electrical circuits and other microstructured components are conventionally produced by applying a
10 plurality of structured layers to a suitable substrate which, for example, may be a silicon wafer. In order to structure the layers, they are first covered with a photoresist which is sensitive to light of a particular wavelength range, for example light in the deep ultraviolet (DUV) spectral range.
15 The wafer coated in this way is subsequently exposed in a projection exposure apparatus. A pattern of diffracting structures, which is arranged on a mask, is projected onto the photoresist with the aid of a projection objective. Since the imaging scale is generally less than 1, such projection
20 objectives are also often referred to as reduction objectives.

- 2 -

After the photoresist has been developed, the wafer is subjected to an etching process so that the layer becomes structured according to the pattern on the mask. The remaining photoresist is then removed from the other parts of the layer. This process is repeated until all the layers have been applied to the wafer.

One of the essential aims in the development of projection exposure apparatuses used for production is to be able to lithographically define structures with smaller and smaller dimensions on the wafer. Small structures lead to high integration densities, and this generally has a favourable effect on the performance of the microstructured components produced with the aid of such systems.

The size of the structures which can be defined depends primarily on the resolution of the projection objective being used. Since the resolution of the projection objectives is proportional to the wavelength of the projection light, one way of increasing the resolution is to use projection light with shorter and shorter wavelengths. The shortest wavelengths used at present are in the deep ultraviolet (DUV) spectral range, namely 193 nm and 157 nm.

Another way of increasing the resolution is based on the idea of introducing an immersion liquid with a high refractive index into an intermediate space which remains between a last lens on the image side of the projection objective and the photoresist or other photosensitive layer to be exposed.

- 3 -

- Projection objectives which are designed for immersed operation, and which are therefore also referred to as immersion objectives, can achieve numerical apertures of more than 1, for example 1.3 or 1.4. The immersion moreover not only allows high numerical apertures and therefore an improved resolution, but also has a favourable effect on the depth of focus. The greater the depth of focus is, the less stringent are the requirements for exact positioning of the wafer in the image plane of the projection objective.
- Carrying out immersed operation, however, requires considerable extra outlay on construction and process technology. For example, it is necessary to ensure that the optical properties of the immersion liquid are spatially homogeneous and constant as a function of time, at least in the volume exposed to the projection light, even if the substrate with the photosensitive layer applied to it moves relative to the projection objective. The technological difficulties associated with this have not yet been resolved satisfactorily.
- It has therefore been considered expedient that projection objectives designed for dry operation, which will be referred to below as "dry objectives" for short, should be operated in immersion only during particularly critical process steps. Of course, with a objective designed for dry operation it is not possible to increase the numerical aperture since this requires a different configuration of the projection objective. Nevertheless, a higher depth of focus is achieved

- 4 -

even in the immersed operation of dry objectives, and this can be advantageous in particularly critical process steps. The dry objective may be used without an immersion liquid in the less critical process steps, so that the exposure of the
5 wafer is simplified considerably and, as a general rule, can be carried out more rapidly.

However, the introduction of an immersion liquid into the immersion space will affect the imaging by the projection objective in such a way that major adjustments to the dry
10 objective have to be carried out before the immersed operation commences. Such adjustments are described in US 2004/109237 A1. The original state has to be restored for a subsequent change to dry operation, which again entails significant costs. Of course, it is also possible to
15 configure the dry objective a priori so that it can be operated in immersion. The numerical aperture must then remain less than 1, since otherwise total reflection would occur at particular optical surfaces during the dry operation. But in this case, too, adjustments are necessary for a change
20 to dry operation since the removal of immersion liquid naturally also affects the imaging.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide a projection objective in which a change from dry operation to
25 immersed operation, and vice versa, can be carried out in a straightforward way.

- 5 -

This object is achieved by a projection objective having a last optical element on the image side which is plane on the image side and which, together with an image plane of the projection objective, delimits an immersion space in the direction of an optical axis of the projection objective, which can be filled with an immersion liquid. At least one liquid or solid volume having plane-parallel interfaces can be introduced into the beam path of the projection objective, the optical thickness of the at least one volume being at least substantially equal to the optical thickness of the immersion space.

The invention is based on the idea that the immersion liquid introduced into the immersion space is comparable to a plane-parallel plate in terms of its optical effect. The relocation of a plane-parallel plate does not affect the focal length when such a relocation takes place only over optical elements without any refractive power. The correction of a wide variety of imaging errors is likewise not compromised by such a relocation of a plane-parallel plate. If, instead of the immersion liquid, a volume which has the same optical thickness as the volume previously filled with immersion liquid in the immersion space, that is to say the same product of refractive index and geometrical thickness, is introduced into the beam path of the projection objective, this is therefore equivalent to merely relocating a plane-parallel plate along the optical axis. If the immersion liquid is removed and the said volume is introduced into the beam path to replace it when changing from immersed operation

- 6 -

to dry operation, this therefore does not affect the focal length of the projection objective. Similar considerations apply to the converse case, that is to say when changing from dry operation to immersed operation. Here, the volume is
5 removed from the beam path and immersion liquid is introduced into the immersion state space instead.

Since a plane-parallel plate can be divided into a plurality of thinner individual plates without changing the optical effect, it is also possible to introduce a plurality of
10 volumes into the beam path instead of just one volume with the aforementioned properties when the immersion liquid is removed. The total optical thickness of all the volumes which are introduced in the direction of the optical axis should then be substantially equal to the dimension of the immersion
15 space in this direction.

It is preferable for the refractive index of the at least one volume to be substantially equal to the refractive index of the immersion liquid, and for the sum of the dimensions of all the volumes which can be introduced in the direction of
20 the optical axis to be at least equal to the dimension of the immersion space in this direction. Preferably, the sum of the dimensions of all the volumes which are introduced in the direction of the optical axis differs by at most 10 nm, preferably at most 1 nm, more preferably at most 0.1 nm, from
25 the dimension of the immersion space in this direction.

- 7 -

As mentioned above, a relocation of a plane-parallel plate has no optical effect if the relocation takes place only over optical elements without any refractive power. Therefore, only refractive surfaces which are plane and extend parallel
5 to the image plane should be arranged in the beam path between the image plane and the volume furthest away from the image plane. The last optical element on the image side is therefore preferably a plane-parallel terminating plate. Some refractive surfaces between the intermediate space and the
10 image plane could nevertheless be reprocessed in order to achieve a corrective effect, so that this condition is then no longer fulfilled, or at least no longer exactly fulfilled.

It is particularly straightforward to introduce or remove the said volume into and from the beam path when the volume is
15 liquid and the projection objective has a sealable intermediate space, for holding at least one liquid volume, between two optical elements whose mutually facing interfaces are plane-parallel. An intermediate space can be filled very completely with liquids in a straightforward way. Furthermore,
20 fewer refractive surfaces overall need to be processed with high accuracy than in the case of an additional plane-parallel plate, which is intended to replace the immersion liquid in terms of its effect on the focal length.

In the simplest case, such an intermediate space which can be
25 filled with liquid is bounded on the image side by the terminating plate. The intermediate space which can be filled with liquid therefore lies on the rear side of the

- 8 -

terminating plate; in order to bound the intermediate space on the object side, it is then necessary to have another refractively acting optical element whose surface on the image side is plane.

5 Since the optical properties of the liquids with which the immersion space and the intermediate space are alternately filled must be exactly equal, an identical liquid should be used for filling the immersion space and the intermediate space. It is even feasible to use the same liquid. This would
10 mean that the liquid introduced into the immersion space was previously in the intermediate space, and vice versa, so that a relocation of the liquid is in fact involved. Since the liquid comes in contact with the photosensitive layer during immersed operation, the liquid may become contaminated during
15 immersed operation. The liquid should therefore be purified before it is returned to the intermediate space.

In principle, the intermediate space as well as the immersion space may be filled and emptied by hand, for example with the aid of a pipette. Preferably, however, an immersion device by
20 which the intermediate space and/or the immersion space can be filled with liquid and emptied is provided for this purpose. Since the liquid introduced in each case should have a maximally uniform temperature, such an immersion device may also comprise a liquid circuit in which the liquid is
25 continuously circulated. In this way, the liquid can be progressively purified and brought to the intended temperature.

- 9 -

Instead of an intermediate space being filled with a liquid, the said volume may also be formed by a plane-parallel plate which has the same refractive index as the immersion liquid, with which the immersion space can be filled.

5 BRIEF DESCRIPTION OF THE DRAWINGS

Various features and advantages of the present invention may be more readily understood with reference to the following detailed description taken in conjunction with the accompanying drawing in which:

- 10 Figure 1 shows a meridian section through a microlithographic projection exposure apparatus according to a first exemplary embodiment of the invention, in a schematic representation which is not true to scale;
- 15 Figure 2a shows an enlarged detail of the end on the image side of the projection objective as shown in Figure 1, during dry operation;
- Figure 2b shows the end on the image side in Figure 2a, but during immersed operation;
- 20 Figure 3a shows a detail corresponding to Figure 2a, of a projection objective according to a second exemplary embodiment of the invention during dry operation;

- 10 -

Figure 3b shows the end on the image side in Figure 3a, but during immersed operation;

Figure 4a shows a detail corresponding to Figure 2a, of a projection objective according to a third
5 exemplary embodiment of the invention during dry operation;

Figure 4b shows the end on the image side in Figure 4a, but during immersed operation;

Figure 5a shows a detail corresponding to Figure 2a, of a
10 projection objective according to a fourth exemplary embodiment of the invention during dry operation;

Figure 5b shows the end on the image side in Figure 5a, but during immersed operation;

15 Figure 6a shows a detail corresponding to Figure 2a, of a projection objective according to a fifth exemplary embodiment of the invention during dry operation;

Figure 6b shows the end on the image side in Figure 6a, but
20 during immersed operation.

- 11 -

DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 shows a meridian section through a microlithographic projection exposure apparatus, denoted overall by 10, during immersed operation in a highly simplified representation which is not true to scale. The projection exposure apparatus 10 has an illumination device 12 for the generation of projection light 13, which comprises a light source 14, illumination optics indicated by 16 and a diaphragm 18. In the exemplary embodiment which is represented, the projection light 13 has a wavelength of 193 nm.

The projection exposure apparatus 10 furthermore includes a projection objective 20 which contains a multiplicity of lenses, only some of which denoted by L1 to L4 are represented by way of example in Figure 1 for the sake of clarity. The projection objective 20 furthermore contains a plane-parallel plate 21 as the last optical element, as well as a likewise plane-parallel terminating plate 23 which terminates the projection objective 20 on the image side. The lenses L1 to L4, the plate 21 and the terminating plate 23 consist of quartz glass. Nevertheless, other materials which have sufficient optical transparency at the wavelength of the projection light 13 may also be selected as the material.

The projection objective 20 is used to project a reduced image of a mask 24, which is arranged in an object plane 22 of the projection objective 20, onto a photosensitive layer 26. The layer 26, which for may example consist of a

- 12 -

photoresist, is arranged in an image plane 28 of the projection objective 20 and is applied to a support 30.

The support 30 is fastened on the bottom of an open-topped container 32 in the form of a trough, which can be displaced
5 (in a way which is not represented in detail) parallel to the image plane 28 with the aid of a displacement device. The container 32 is filled sufficiently with an immersion liquid 34 so that the projection objective 20 is immersed with its terminating plate 23 in the immersion liquid 34 during
10 operation of the projection exposure apparatus 10. The immersion liquid 34 may, for example, be highly pure deionised water or a halogen-free oil. The immersion liquid 34 chosen in the represented exemplary embodiment is nitrobenzene, whose refractive index at the wavelength of the
15 projection light 13 being used is approximately equal to the refractive index of quartz glass, of which the plate 21 and the terminating plate 23 are made.

Via a feed line 36 and a discharge line 38, the container 32 is connected to a treatment unit 40 which contains, inter
20 alia, a circulating pump and a filter for purifying the immersion liquid 34. The treatment unit 40, the feed line 36, the discharge line 38 and the container 32 together form an immersion device denoted by 42, in which the immersion liquid 34 circulates while being purified and kept at an at least
25 approximately constant temperature.

- 13 -

The immersion device 42 furthermore includes another line 44, which leads directly to the projection objective 20. Via the line 44, when changing from immersed operation to dry operation and vice versa, immersion liquid 34 can be pumped
5 into or removed from an intermediate space which is located between the terminating element 23 and the plane-parallel plate 21.

This will be explained in more detail below with reference to Figures 2a and 2b, which show the end on the image side of
10 the projection objective 20 in an enlarged representation during dry operation and immersed operation, respectively. It can be seen in Figure 2a that an intermediate space 46, which remains between the plane-parallel plate 21 and the terminating plate 23, is sealed tightly all around. An
15 annular sealing element 48, which is clamped between two element frames indicated by 50, 52, is used for this purpose. The element frames 50, 52 make it possible to align the plane-parallel plate 21 and the terminating plate 23, as is known per se in the prior art. The line 44 extends through
20 the sealing element 48 into the intermediate space 46.

The plane-parallel plate 21 and the terminating plate 23 are aligned so that their mutually facing plane interfaces 56, 58 are aligned exactly parallel with a distance d_1 between them. When the intermediate space 46 is filled with immersion
25 liquid 34 during dry operation, as represented in Figure 2a, the intermediate space acts like a plane-parallel plate made

- 14 -

of a material whose refractive index is equal to that of the immersion liquid 34.

Peripheral rays of the projection light 13, which pass through the projection objective 20 onto the photosensitive layer 26, are indicated by 60 and 62 in Figure 2a. Since the refractive index of the immersion liquid 34 is substantially equal to the refractive indices of the plane-parallel plate 21 and of the terminating plate 23, the projection light 13 is almost not refracted at all when it passes through the intermediate space 46 filled with immersion liquid 34. The maximum aperture angle at which the peripheral rays 60, 62 meet at points on the photosensitive layer 26 is denoted by α in Figure 2.

If a change is then to be made to the immersed operation as shown in Figures 1 and 2b, the immersion liquid 34 will be pumped out of the intermediate space 46 via the line 44. After having been purified in the immersion device 42, the immersion liquid 34 is then introduced via the feed line 36 into the container 32 where it enters an immersion space 64, which is formed between the terminating plate 23 and the photosensitive layer 26. The projection objective 20 is in this case designed so that the height d_1 of the intermediate space 46 is equal to the height d_2 of the immersion space 64. The change from dry operation to immersed operation can therefore be readily understood as entailing relocation of a plane-parallel "plate" of immersion liquid 34 from the intermediate space 46 into the immersion space 64. Since this

- 15 -

"plate" does not thereby change its thickness and since the optical element lying in between, namely the terminating plate 23, has plane-parallel interfaces, even after the change to immersed operation the peripheral rays denoted by 5 60' and 62' in Figure 2b still meet at a point in the image plane 28 where the photosensitive layer 26 is arranged.

As can be seen in Figure 2b, the maximum aperture angle denoted by α' has become smaller because of the change from dry operation to immersed operation. This is associated with 10 an increase in the depth of focus since, when the photosensitive layer 26 is moved out of the image plane 28, the broadening of the focal point into a focal spot is less than the case of the dry operation as represented in Figure 2a.

15 A second exemplary embodiment of a projection objective will be explained below with reference to Figures 3a and 3b, which are representations corresponding to Figures 2a and 2b. Parts which are the same are denoted by identical reference numerals, and parts which correspond to one another are 20 denoted by reference numerals increased by 100. Wherever reference numerals increased by 100 are not explicitly mentioned in the text, then the comments made above about Figures 2a and 2b apply accordingly.

The projection objective 120 differs from the projection 25 objective 20 as shown in Figures 2a and 2b essentially in that the projection objective 120 does not have a plane-

- 16 -

parallel plate 21. Instead, the last optical element with non-zero refractive power in the projection objective 120 as shown in Figures 3a and 3b is a planoconvex lens L104.

Together with an opposing plane surface 158 of a terminating
5 plate 123, its plane surface 156 on the image side forms an intermediate space 146 of height d_1 , which can be filled with immersion liquid 34. In terms of function, the projection objective 120 does not substantially differ from the projection objective 20 as shown in Figures 2a and 2b. In
10 particular, the intended reduction of the aperture angle α and therefore the increase of the depth of focus also take place here when changing to immersed operation.

A third exemplary embodiment of a projection objective will be explained below with reference to Figures 4a and 4b, which
15 are representations corresponding to Figures 2a and 2b. Parts which are the same are denoted by identical reference numerals, and parts which correspond to one another are denoted by reference numerals increased by 200. Wherever reference numerals increased by 200 are not explicitly
20 mentioned in the text, then the comments made above about Figures 2a and 2b apply accordingly.

The projection objective 220 as shown in Figures 4a and 4b differs from the projection objective 120 as shown in Figures 3a and 3b essentially in that the terminating plate 123 is
25 divided into two individual plane-parallel plates 223a and 223b. The respective thicknesses a_a and a_b of the plates 223a

- 17 -

and 223b now add up to the thickness a of the terminating plate 123 as shown in Figures 3a and 3b.

The division of the terminating plate 123 into two individual plane-parallel plates 223a and 223b also partitions the
5 immersion space 146 above the terminating plate 123 into two intermediate spaces 246a and 246b, the respective heights d_{1a} and d_{1b} of which add up to equal the height d_1 of the intermediate space 146 and therefore to equal the distance d_2 between the terminating plate 223b on the image side and the
10 image plane 28. On account of the separate intermediate spaces 246a and 246b, there are also two separate lines 244a, 244b by which the intermediate spaces 246a, 246b can be filled with immersion liquid 34, or this can be pumped out of them. When changing from dry operation to immersed operation,
15 as indicated between Figures 4a and 4b, the maximum aperture angle α is here again reduced so that the depth of focus of the projection is improved.

A fourth exemplary embodiment of a projection objective will be explained below with reference to Figures 5a and 5b, which
20 are representations corresponding to Figures 2a and 2b. Parts which are the same are denoted by identical reference numerals, and parts which correspond to one another are denoted by reference numerals increased by 300. Wherever reference numerals increased by 300 are not explicitly
25 mentioned in the text, then the comments made above about Figures 2a and 2b apply accordingly.

- 18 -

The projection objective 320 as shown in Figures 5a and 5b differs from the projection objective 120 as shown in Figures 3a and 3b essentially in that the intermediate space 146 between the terminating plate 123 and the planoconvex lens L104 arranged above it cannot be filled with a liquid. Instead, the projection objective 320 is designed so that a plane-parallel plate 334 which also consists of quartz glass, and which therefore has approximately the same refractive index as the immersion liquid 34, can be introduced into the intermediate space 346 (see arrow P). The thickness d_1 of the plate 334 is in this case the same as the height d_2 of the immersion space 64. The plate 334 is removed from the beam path when changing to immersed operation.

A fifth exemplary embodiment of a projection objective will be explained below with reference to Figures 6a and 6b, which are representations corresponding to Figures 2a and 2b. Parts which are the same are denoted by identical reference numerals, and parts which correspond to one another are denoted by reference numerals increased by 400. Wherever reference numerals increased by 400 are not explicitly mentioned in the text, then the comments made above about Figures 2a and 2b apply accordingly.

The projection objective 420 as shown in Figures 6a and 6b differs from the projection objective 320 as shown in Figures 5a and 5b essentially in that the lens L404 is a meniscus lens instead of a planoconvex lens. During dry operation, therefore, the plane-parallel plate 334 is not inserted into

- 19 -

an intermediate space between two plane and parallel interfaces as in the case of the projection objective 320 in Figures 5a and 5b, but merely rests on the plane surface 458 on the object side of the terminating plate 423 (which is
5 thinner in this case).

The advantage of the projection objectives 320 and 420, in which respective plane-parallel plates 334 and 434 are introduced into the beam path for dry operation, is primarily that it is not necessary to provide specially dimensioned
10 intermediate spaces as was the case for the projection objectives 20, 120 and 220. Complete reconfiguration of the projection objectives is therefore unnecessary. Instead, it is sufficient to start off with "normal" dry operation and then accommodate the additional plates 334 or 434 by
15 modifications such as those described, for example, in US 2004/109237 A1. Such a modification can be carried out with the aid of liquid lenses whose refractive power is variable.

- 20 -

CLAIMS

1. Projection objective of a microlithographic projection exposure apparatus (10), having a last optical element (23; 123; 223; 323; 423) on the image side which is plane on
5 the image side and which, together with an image plane (28) of the projection objective (20; 120; 220; 320; 420), delimits an immersion space (64) in the direction of an optical axis (54) of the projection objective, which can be filled with an immersion liquid (34),
- 10 characterised in that
- at least one liquid or solid volume (34, 46, 34a, 34b, 246a, 246b; 334; 434) having plane-parallel interfaces (56, 58; 156, 158) can be introduced into the beam path of the projection objective (20; 120; 220; 320; 420), the optical thickness of
15 the at least one volume (34, 46, 34a, 34b, 246a, 246b; 334; 434) being at least substantially equal to the optical thickness of the immersion space (64).
2. Projection objective according to Claim 1, characterised in that only refractive surfaces which are plane and
20 extend parallel to the image plane (28) are arranged in the beam path between the image plane (28) and the volume furthest away from the image plane (28).

- 21 -

3. Projection objective according to Claim 2, characterised in that the last optical element on the image side is a plane-parallel terminating plate (23; 123; 223; 323; 423).
4. Projection objective according to one of the preceding
5 claims, characterised in that the refractive index of the at least one volume (34, 46, 34a, 34b, 246a, 246b; 334; 434) is substantially equal to the refractive index of the immersion liquid (34), and the sum of the dimensions (d_1 ; d_{1a} , d_{1b}) of all the volumes which can be introduced in the
10 direction of the optical axis (54) is at least equal to the dimension (d_2) of the immersion space (64) in this direction.
5. Projection objective according to Claim 4, characterised in that the sum of the dimensions (d_1 ; d_{1a} , d_{1b}) of all the volumes which can be introduced in the direction of the
15 optical axis (54) differs by at most 10 nm, preferably at most 1 nm, more preferably at most 0.1 nm, from the dimension (d_2) of the immersion space (64) in this direction.
6. Projection objective according to one of the preceding claims, characterised in that in order to hold at least
20 one liquid volume (34; 34a, 34b), the projection objective (20; 120, 220) has a sealable intermediate space (46; 146; 246a, 246b) between two optical elements (21, 23; L104, 123; L204, 223a, 223b) whose mutually facing interfaces (56, 58; 156, 158) are plane-parallel.

- 22 -

7. Projection objective according to Claim 3 and according to Claim 6, characterised in that the intermediate space (46; 146; 246b) is bounded on the image side by the terminating plate (23; 123; 223).
- 5 8. Projection objective according to Claim 6 or 7, characterised in that the projection objective (20) has an immersion device (42) for filling the intermediate space (46) with liquid (34) and for emptying the intermediate space (46).
- 10 9. Projection objective according to one of the preceding claims, characterised in that at least one volume is formed by a plane-parallel plate (334; 434) which has the same refractive index as the immersion liquid (34), with which the intermediate space (64) can be filled.
- 15 10. Microlithographic projection exposure apparatus comprising a projection objective (20; 120; 220; 320; 420) according to one of the preceding claims.
11. Method for converting a projection objective of a microlithographic projection exposure apparatus from dry
20 operation to immersed operation, having the following steps:
- a) providing a projection objective (20; 120; 220; 320; 420) having a last optical element (23; 123; 223; 323; 423) on the image side which is plane on the image side and which, together with an image plane (28) of the

- 23 -

projection objective, delimits an immersion space (64) in the direction of an optical axis (54) of the projection objective, which can be filled with an immersion liquid (34);

- 5 b) removing at least one liquid or solid volume (34, 34a, 34b, 246a, 246b; 334; 434) which has plane-parallel interfaces and whose refractive index is substantially equal to the refractive index of the immersion liquid (34) from the beam path of the projection objective, the
10 optical thickness of the at least one volume (34, 46, 34a, 34b, 246a, 246b; 334; 434) being at least substantially equal to the optical thickness of the immersion space (64);
- c) filling the immersion space (64) with liquid (34) which
15 has the same refractive index as the volume (34, 46, 34a, 34b, 246a, 246b; 334; 434) removed in step b).

12. Method according to Claim 11, characterised in that a liquid (34) is removed in step b) and relocated into the immersion space (64).
- 20 13. Method according to Claim 11 or 12, characterised in that after exposures have been carried out in immersed operation, the projection objective is converted to dry operation by removing the liquid (34) from the immersion space and re-introducing the at least one volume (34, 34a,

- 24 -

34b, 246a, 246b; 334; 434) removed in step b) into the beam path of the projection objective.

14. Method for the microlithographic production of microstructured components, having the following steps:

- 5 a) providing a support (30), on at least some of which a layer (26) of a photosensitive material is applied;
 - b) providing a reticle (24) which contains structures to be projected
 - c) providing a projection objective (20; 120, 220; 320; 420)
10 according to one of Claims 1 to 9;
 - d) projecting at least a part of the reticle (24) onto a region on the layer (26) with the aid of the projection objective (20; 120, 220; 320; 420).
- 15 15. Microstructured component which is produced by a method according to Claim 14.

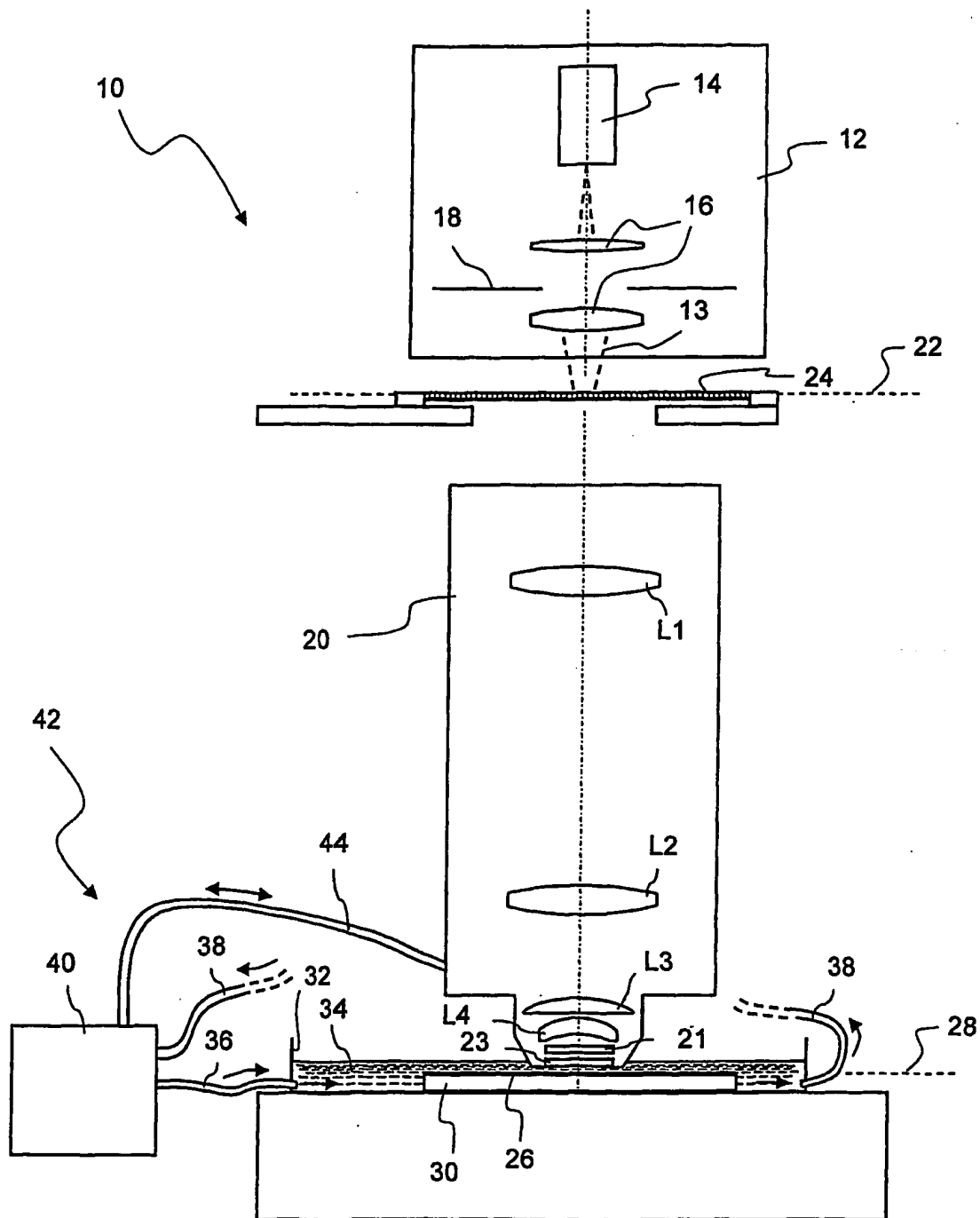


Fig. 1

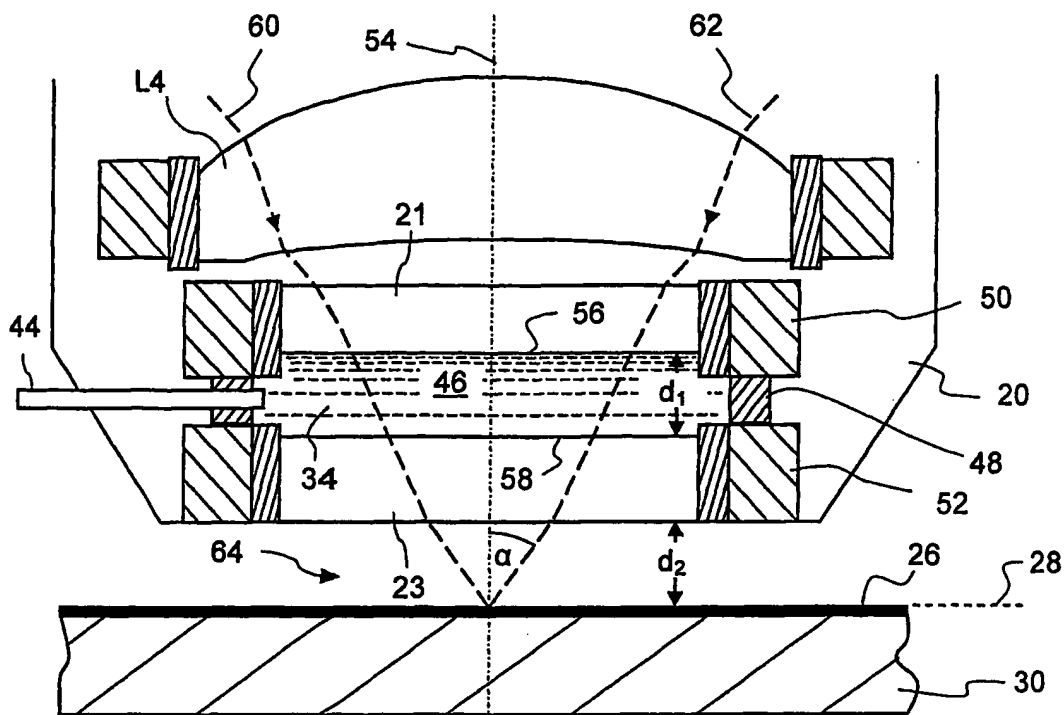


Fig. 2a

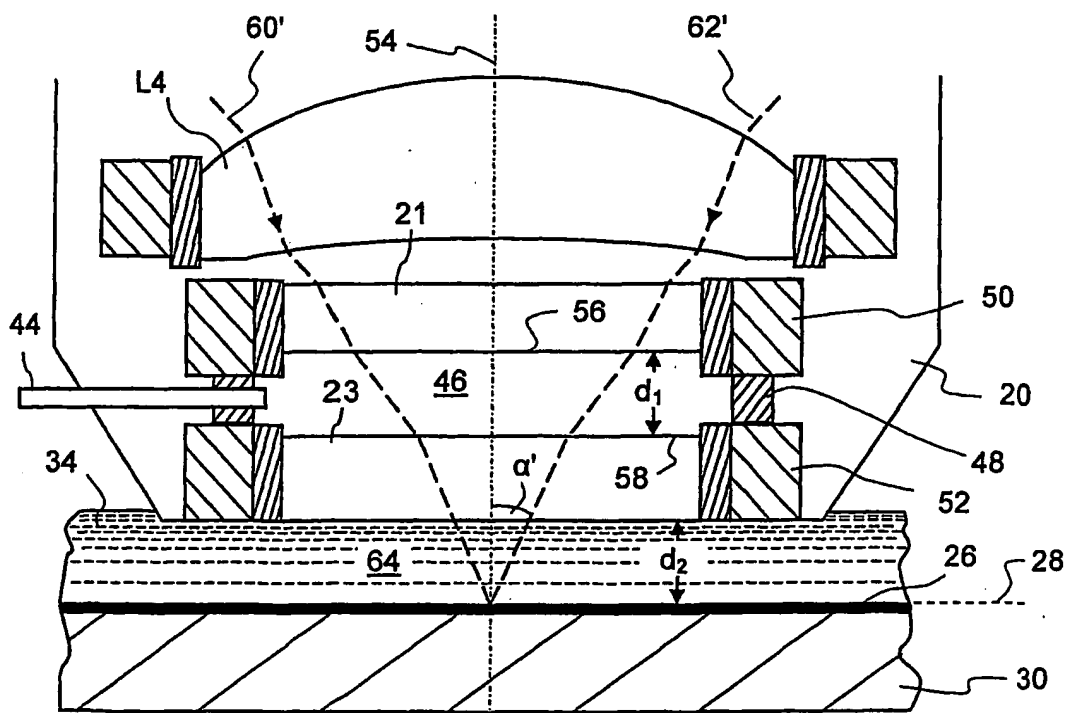
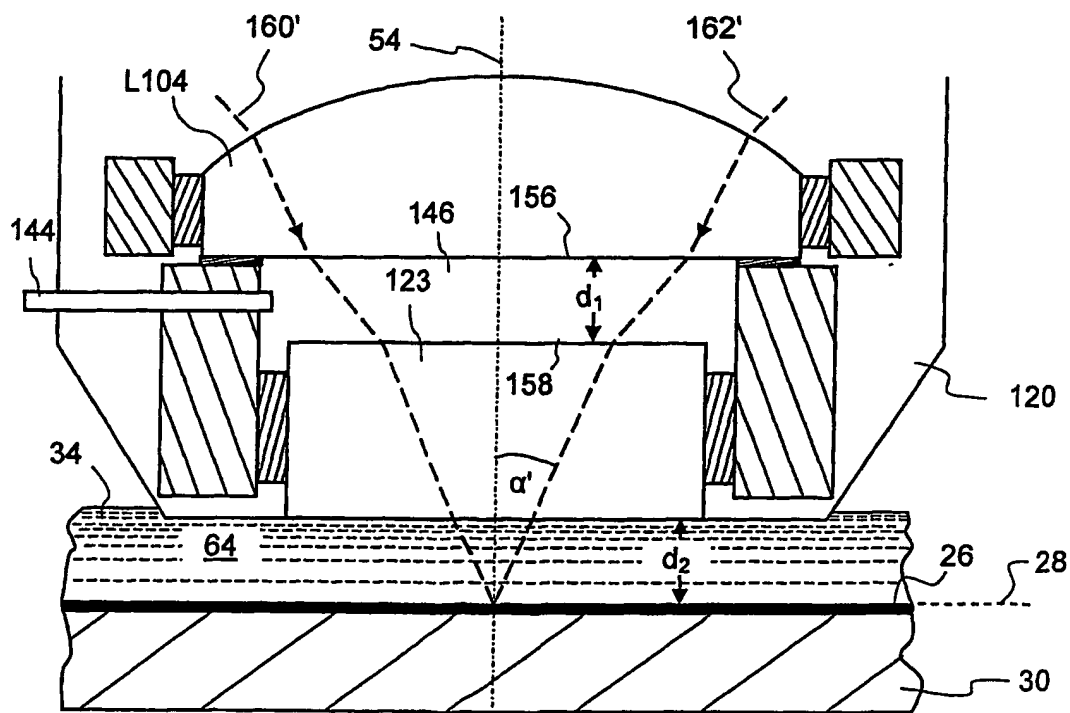
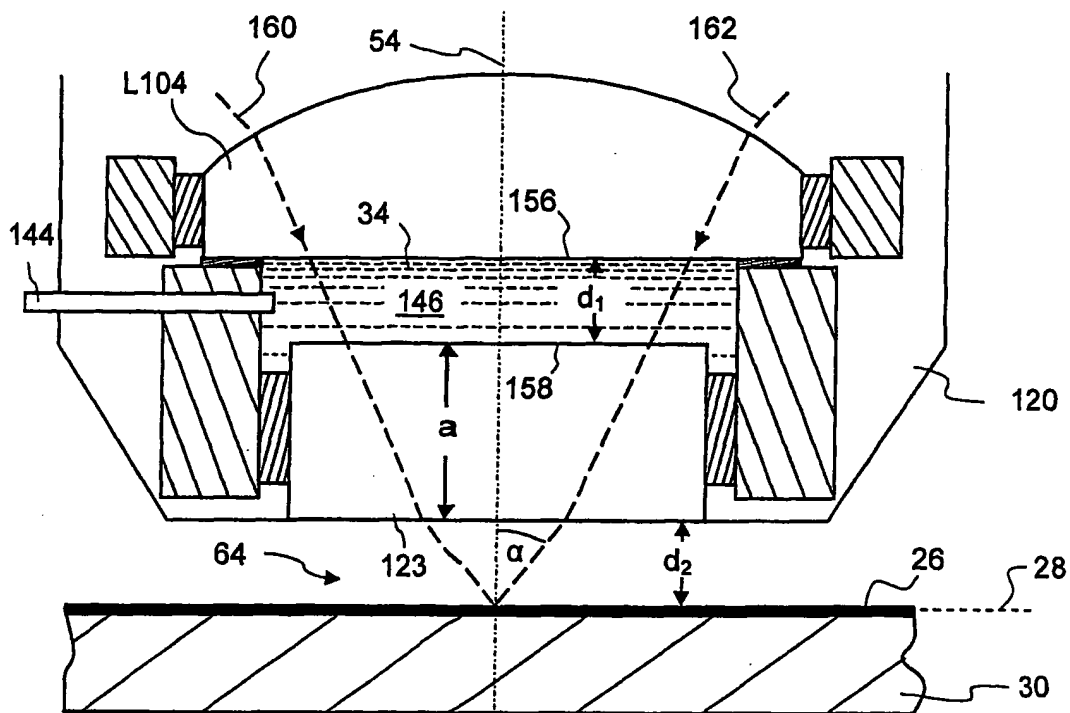
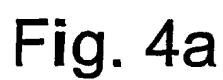


Fig. 2b





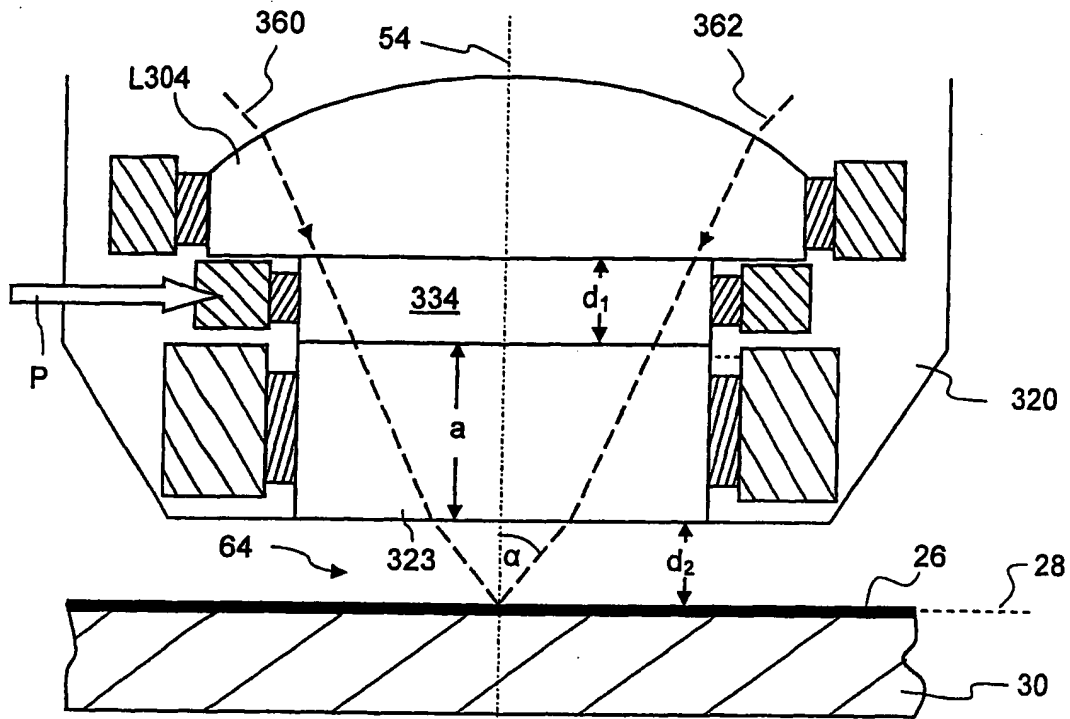


Fig. 5a

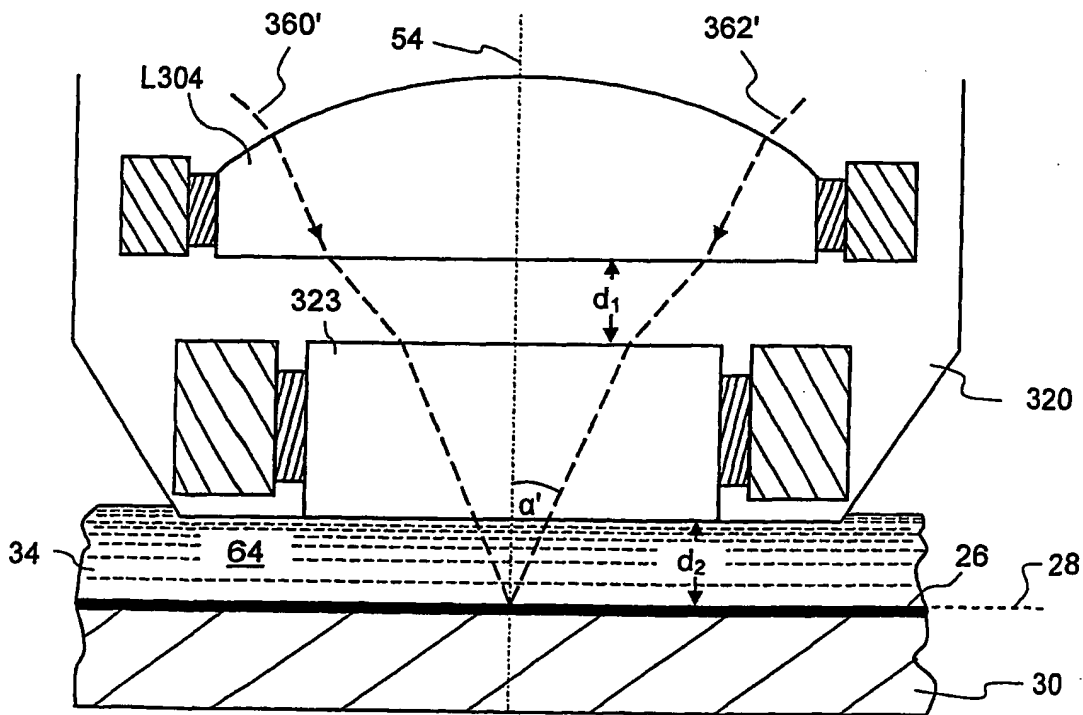


Fig. 5b

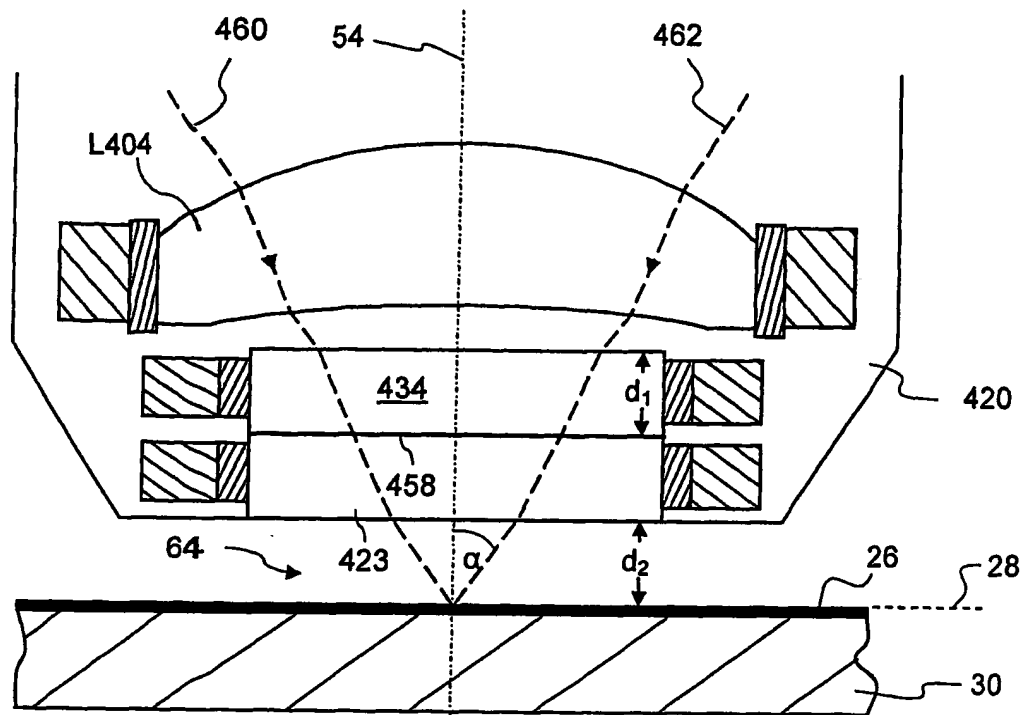


Fig. 6a

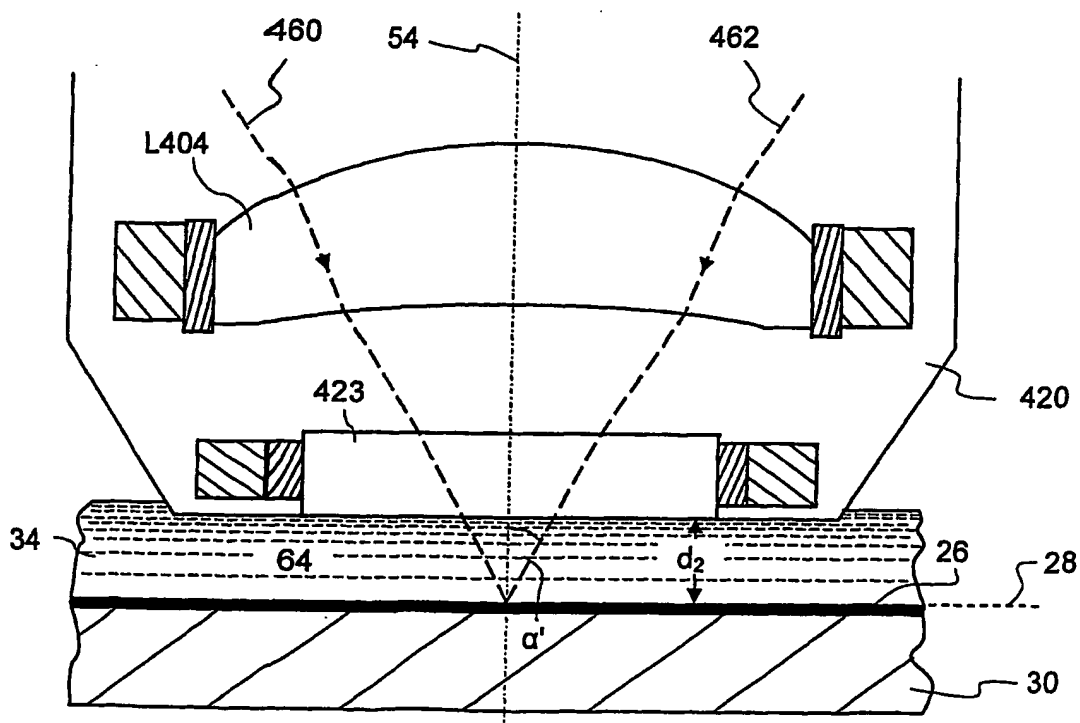


Fig. 6b

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP2005/000641

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G03F7/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DD 224 448 A1 (VEB CARL ZEISS JENA, DD) 3 July 1985 (1985-07-03)	1, 10, 14
A	page 4 - page 6; figures 1-3	11
X		15
Y	EP 0 638 847 A (NIKON CORPORATION) 15 February 1995 (1995-02-15) column 5, line 42 - line 50 column 12, line 35 - line 41	1, 10, 14
P, Y	EP 1 431 826 A (CARL ZEISS SMT AG) 23 June 2004 (2004-06-23) cited in the application columns 60, 61	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- *G* document member of the same patent family

Date of the actual completion of the international search

6 June 2005

Date of mailing of the international search report

14/06/2005

Name and mailing address of the ISA

European Patent Office, P.B. 5618 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Eisner, K

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/EP2005/000641

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
DD 224448	A1	03-07-1985	NONE	
EP 0638847	A	15-02-1995	JP 3291849 B2	17-06-2002
			JP 7029808 A	31-01-1995
			DE 69415610 D1	11-02-1999
			DE 69415610 T2	22-07-1999
			DE 69433142 D1	16-10-2003
			DE 69433142 T2	01-04-2004
			EP 0638847 A1	15-02-1995
			EP 0834771 A1	08-04-1998
			US 5448336 A	05-09-1995
			US 6304317 B1	16-10-2001
			US 2002008863 A1	24-01-2002
EP 1431826	A	23-06-2004	DE 10258718 A1	24-06-2004
			EP 1431826 A2	23-06-2004
			JP 2004191920 A	08-07-2004
			US 2004109237 A1	10-06-2004